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Effects of planting dates, densities, and varieties on ecophysiology of pigeonpea in the Southeastern United States

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ABSTRACT

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is an important legume crop widely cultivated in tropical and subtropical climates of the world. Interest in this crop is growing in many countries because of its multiple uses as a source of food, feed, fuel, and fertilizer. However, the performance of pigeonpea in Southeastern US has not been well investigated. We conducted an experiment in Nashville, Tennessee to test the effects of two planting dates, three densities, and four varieties on pigeonpea ecophysiology that included leaf photosynthesis, stomatal conductance, transpiration, water use efficiency (WUE), leaf area index (LAI) and soil respiration. Results indicated that the plants in the late planting plots had higher photosynthetic rate, stomatal conductance and transpiration. There were significant differences in the levels of leaf photosynthesis, stomatal conductance, transpiration, WUE and LAI among all four varieties. W3 and G1 showed higher photosynthetic rate and LAI than W1, and W3 had higher WUE than G2 and W1. Planting densities had no significant effect on all variables studied. This study indicated that late planting of variety G1 or W3 resulted in higher WUE and yield, but did no significant influence soil CO_2 emission.

Keywords: Leaf Area Index; Photosynthesis; Soil Respiration; Transpiration; Water Use Efficiency

1. INTRODUCTION

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is well adapted to arid and semi-arid tropical and subtropical climates of the world [1-3]. Pigeonpea is the sixth most important legume food crop globally and is grown on about 5 million ha of land [4]. Currently, pigeonpea is widely cultivated in India [5]. Uganda and Kenya in Africa; the West Indies, Puerto Rico, and the Dominican Republic in the Caribbean region; and Burma in Asia are also major pigeon-pea-producing countries [6-8]. Pigeonpea is a nutritious high protein crop with high digestible protein (68%), low in fat and sodium with no cholesterol and has high dietary fibers [9]. Interest in this crop is growing in many other countries because of its multiple uses as a source of food, feed, fuel, and fertilizer [10-12]. During the three years of 1997-1999, the consumption of dry edible beans per person in the US has increased by 28% over the 1987-89 period to 3.5 kg [13]. It has been postulated that a combination of rising immigration (particularly among the Hispanic population), wide-spread interest in ethnic foods cooked dry beans, and changes in America's dietary awareness and sophistication have contributed to the rising per capita dry bean use [13]. It would be a great blessing to the rural community if this crop could be grown in the Southeast region of US. Since most of the agronomic practices used for the production of pigeon-pea are similar to soybean, pigeonpea appears to be a promising new legume crop for sale in the southern US.

Previous studies on pigeonpea have been conducted mostly in India and in the tropical and subtropical regions of the world [7,10,12,14]. Pigeonpea is tolerant to low phosphorus supply and acid soils, and grows well in the phosphorus-deficient soils of the tropical environment [15]. Faroda and Johri (1981) found that row spacings from 25 to 40 cm and plant spacing of 20 cm is suitable for early and extra early varieties of pigeonpea [16]. Despite the potential for pigeonpea as an important leguminous and vegetable crop, only a few studies have been conducted in the US on its adaptability to various climatic conditions such as low and uncertain summer rainfall or on its canopy development in temperate regions [11,17-20]. Several varieties have been developed in Georgia and Mississippi and tested in Florida, Oklahoma and Virginia for grain and forage production [11, 19,21]. Experiments conducted by Rao *et al.* (2002) showed that pigeonpea has the potential to produce moderate-quality forage during the forage deficit period from August through October in the Southern US Great Plains [11]. Bhardwaj *et al.* (1999) also reported that determinate pigeonpea varieties out-yielded indeterminate varieties (1751 vs 721 kg/ha) [21]. The green bean yield of pigeonpea varied from 11,888 to 15,696 kg/ha. Rao *et al.* (2009) found that pigeonpea had similar aboveground biomass, accumulated less nitrogen, lower digestibility than soybean and guar, and could provide producers in the Southern Great Plains with options other than soybean for generating forage or biological nitrogen [19].

The objective of this study was to quantify the ecophysiological responses of pigeonpea to planting dates, plant densities, and four varieties in terms of leaf physiology, leaf area development and soil respiration. We believe that such information concerning pigeonpea will be useful for crop improvement and possible biofuel production programs.

2. MATERIALS AND METHODS

2.1. Experimental Site, Experimental Design, and Treatments

Field experiments were conducted on the Tennessee State University Agricultural Research Center (Latitude 36.12'N, Longitude 36.98'W, elevation 127.6 m) in Nashville, Tennessee, in 2010. The experimental site was an Armour silt loam soil, slightly acidic (pH = 6.2), low in both phosphorus and potassium.

We considered varieties, planting dates and densities as treatment factors. Four varieties of pigeonpea were selected for this study: two early maturing varieties (G1: George One and G2: Georgia Two), and two late maturing varieties (W1 and W3). Two planting dates were June 9 and July 1, 2010. Three planting spacings were 5, 10, and 15 cm, equivalent to 295,500, 145,250, and 96,833 pants/ha, respectively.

The experiment was laid out as a split-plot design with four replications. The planting date was as main factors and variety and density were split factors. In each block, varieties and densities were randomly assigned. The total number of plots was 96. Plot size was 3 m × 2 m. Seeds were obtained from a private company in Georgia. Fresh seeds were sown and thinned to pre-determined densities. Normal agricultural practices were used. No nitrogen or irrigation was applied; 130 kg P_2O_5/ha and 80 kg K_2O/ha were surface applied before seeds were planted. Few insect/disease problems were encountered, while weed control was maintained by pre-plant application of a mixture of two herbicides—prowl (EC) at 1.1 kg a.i./ha and fusilade (2E) at 0.28 kg a.i./ha and post-emergence application of basagran (4E) herbicide at 1.1 kg a.i/ha. Total precipitation during the cropping season (June to November) was 683.8 mm, higher than 30 years' average (540.5 mm), but total precipitation in September and October was remarkably lower than 30 years' average (93 mm vs 160 mm) [22].

2.2. Field Measurements of Leaf Photosynthesis, Stomatal Conductance, Transpiration, Leaf Area Index and Soil Respiration

Leaf photosynthesis, stomatal conductance and transpiration rates were measured using a Li-6400 Portable Photosynthesis System (Li-Cor Inc., Lincoln, NE, USA). We selected 2 to 3 plants in the center row of each plot. For each plant, two fully expanded young leaves were measured for leaf photosynthesis. All measurements were conducted during the peak flowering time in September and October between 10:00 am and 3:00 pm. The photosynthetically active radiation (PAR) was set at 2000 μmol photon $m^{-2}\cdot s^{-1}$, and the CO_2 concentration of the air was set at ambient concentration 380 - 400 ppm. Water use efficiency was calculated as leaf photosynthesis/ transpiration.

Leaf area index was measured using a LAI 2200 Plant Canopy Analyzer (Li-COR, Inc., Lincoln, Nebraska, USA). We followed the manufacture's instruction for row crop measurements. Two measurements above the canopy and 6 below were made for each plot, in a sequence of ABBBABBB (A for above canopy and B for below canopy measurements). Measurements were taken near sunset during the peak flowering time.

Soil respiration was measured using the Li-Cor 6400 infrared gas analyzer (Li-COR, Inc., Lincoln, Nebraska, USA) connected to a Li-Cor 6400-09 soil respiration chamber (9.55 cm diameter) (Li-COR, Inc., Lincoln, Nebraska, USA). Two PVC soil collars (80 cm^2 in area and 5 cm in height) were installed about 3 cm deep into the soil in the center row of each plot, a few days before taking the measurements. Soil respiration was measured during the peak flowering time at the same time as for the leaf photosynthesis measurements. These measurements were made between 1:00 pm and 4:00 pm local time. Soil respiration was measured three times for each soil collar. Soil temperature at 5 cm below the soil surface was monitored with a thermocouple sensor attached to the respiration chamber during the soil respiration measurement. Volumetric soil moisture of the top 5 cm soil layer was measured near soil collars using a HydroSense (Campell Scientific Australia Pty. Ltd.) connected with a CS620 sensor at the same time that the soil respiration measurements were taken.

2.3. Statistical Analysis

The effects of planting dates, varieties, and densities using analysis of variance (ANOVA) for a split plot design were evaluated [23]. If the effect was significant, least significant difference (LSD) was used for multiple comparisons. Data analysis was done using SAS software [23,24].

3. RESULTS AND DISCUSSION

The effects of planting dates, densities and varieties on leaf photosynthesis, stomatal conductance, LAI and soil respiration were analyzed using Analysis of variance (ANOVA). Planting dates and varieties of pigeonpea had significant effects on leaf photosynthesis and stomatal conductance (**Table 1**). However, plant density did not influence these variables. For LAI, only varietal effects were significant. Block effect was significant for leaf photosynthesis, stomatal conductance, and LAI. We did not find any significant effect of planting date, varieties, density, or even block on soil respiration.

3.1. Leaf Photosynthesis, Stomatal Conductance, Transpiration and Water Use Efficiency

The maximum leaf photosynthetic rate was 10.99 μmol $CO_2/m^2/s$ for the late planting plots, 17.8% higher than that in the early planting plots (**Table 2**). Among the four varieties, the photosynthetic rate of W1 was 8.97 μmol $CO_2/m^2/s$, which was significantly lower than other three varieties (**Table 3**). Among the other three varieties, there was no significant difference. Plant densities did not influence the photosynthetic rate. For stomatal conductance, plants in the late planting plots had higher stomatal conductance rates (0.087 mol $H_2O/m^2/s$ compared to 0.078 mol $H_2O/m^2/s$ in early planting plots). There was no significant difference among G2, W3 and G1, but W1 had a significant lower stomatal conductance than G2 and W3. No significant difference was found between W1 and G1 (**Table 4**). Plant densities also did not influence stomatal conductance.

Leaf photosynthesis is an important biological process that directly influences plant growth and productivity. Values we measured during the peak flowering times may be similar to those taken at other times but varied among species [25]. The low precipitation during the flowering time in 2010 may have reduced the net leaf photosynthetic rates, but these values were consistent to several other previous studies. For example, Khudsar and Iqbal (2001) measured the leaf net photosynthetic rate at different cadmium concentrations and found that under no cadmium stress, the photosynthetic rate varied from 11.53 μmol $CO_2/m^2/s$ pre-flowering, to 9.50 during flowering and 6.92 post-flowering [26]. Takele and McDavid (1995) reported that net photosynthesis of pigeonpea grown in pots was 12.6 μmol CO_2 $m^{-2}\cdot s^{-1}$ [27]. Net leaf photosynthetic rates varied from 10.9 to 13.9 μmol $CO_2/m^2/s$ among three varieties and stomatal con-

Table 1. Results of Analysis of Variance (ANOVA) to detect the effects of planting dates, varieties and densities on maximum net leaf photosynthetic rate, stomatal conductance, leaf area index and soil respiration of pigeonpea.

Source of Variance	Leaf Photosynthetic Rate (μmol $CO_2/m^2/s$)[a]	Stomatal Conductance (mol $H_2O/m^2/s$)[a]	Transpiration (mmol $H_2O/m^2/s$)[a]	Water Use Efficiency (μmol CO_2/mmol H_2O)[a]	Leaf Area Index (m^2/m^2)[a]	Soil Respiration (μmol $CO_2/m^2/s$)[a]
Model	16.08**	10.40**	14.96**	20.43**	3.21**	1.16
Planting Date	16.25**	4.37*	51.99**	35.89**	0.99	0.25
Block	26.82**	16.85**	15.33**	22.93**	2.21*	1.07
Variety	4.15*	5.56**	10.53**	23.87**	7.94**	1.64
Density	1.65	1.30	1.90	0.05	0.23	1.18

[a]*Indicates significant at 5% level; **indicates significant at 1% level.

Table 2. Mean and significance of maximum leaf photosynthetic rate, stomatal conductance, leaf area index and soil respiration of pigeonpea between planting dates.

Planting Date	Leaf Photosynthetic Rate (μmol $CO_2/m^2/s$)[a]	Stomatal Conductance (mol $H_2O/m^2/s$)[a]	Transpiration (mmol $H_2O/m^2/s$)[a]	Water Use Efficiency (μmol CO_2/mmol H_2O)[a]	Leaf Area Index (m^2/m^2)[a]	Soil Respiration (μmol $CO_2/m^2/s$)[a]
June 6	9.33[a]	0.078[a]	1.72[a]	5.48[a]	2.14[a]	3.19[a]
July 1	10.99[b]	0.087[b]	2.29[b]	4.83[b]	2.24[a]	3.27[a]

[a]Different letters denote significant differences among treatments and same letter denotes no significant difference.

Table 3. Mean and significance of maximum leaf photosynthetic rate, stomatal conductance, leaf area index, and soil respiration of pigeonpea among varieties.

Variety	Leaf Photosynthetic Rate (μmol $CO_2/m^2/s$)[a]	Stomatal Conductance (mol $H_2O/m^2/s$)[a]	Transpiration (mmol $H_2O/m^2/s$)[a]	Water Use Efficiency (μmol CO_2/mmol H_2O)[a]	Leaf Area Index (m^2/m^2)[a]	Soil Respiration (μmol $CO_2/m^2/s$)[a]
G1	10.12[a]	0.079[ab]	1.95[b]	5.40[ab]	2.46[a]	3.30[a]
G2	10.23[a]	0.090[a]	2.31[a]	4.48[c]	1.90[b]	3.35[a]
W1	8.97[b]	0.069[b]	1.68[c]	5.19[b]	2.01[b]	3.01[a]
W3	10.92[a]	0.090[a]	1.94[b]	5.66[a]	2.38[a]	3.31[a]

[a]Different letters denote significant differences among treatments and same letter denotes no significant difference.

Table 4. Mean and significance of maximum leaf photosynthetic rate, stomatal conductance, leaf area index and soil respiration of pigeonpea among planting densities.

Density (plant·ha^{-1})	Leaf Photosynthetic Rate (μmol $CO_2/m^2/s$)[a]	Stomatal Conductance (mol $H_2O/m^2/s$)[a]	Transpiration (mmol $H_2O/m^2/s$)[a]	Water Use Efficiency (μmol CO_2/mmolH_2O)[a]	Leaf Area Index (m^2/m^2)[a]	Soil Respiration (μmol $CO_2/m^2/s$)[a]
96,833	10.37[a]	0.085[a]	2.04[a]	5.12[a]	2.19[a]	3.38[a]
145,250	10.37[a]	0.084[a]	2.03[a]	5.26[a]	2.15[a]	3.19[a]
290,500	9.54[a]	0.076[a]	1.86[a]	5.16[a]	2.22[a]	3.10[a]

[a]Different letters denote significant differences among treatments and same letter denotes no significant difference.

ductance varied from 0.155 to 0.214 mmol $H_2O/m^2/s$ (Fujita *et al.* 2004). But, Lopez *et al.* (1988) reported much higher values of maximum net leaf photosynthesis and stomatal conductance (~22 µmol $CO_2/m^2/s$ and 0.25 mmol $H_2O/m^2/s$) for pot-grown pigeonpea plants measured at PAR of 1700 µmol photon /m^2/s [28].

Tayo (1982) evaluated the growth, development and yield of pigeonpea grown at three different densities of 27,000, 55,000 and 83,000 plants/ha and found that there was a progressive reduction in the development per plant of vegetative characters, dry matter accumulation and yield characters as population densities increased; however, the calculated growth rates (net photosynthesis rate, relative growth rate and leaf area ratio) were more or less the same at each density [29]. Their results were similar to what we found. For same varieties planted at different dates, it appears that pigeonpea planted at a late date had higher net leaf photosynthesis rates. Among the four varieties studied, W3 seems to be more suitable for Middle Tennessee region.

Water use and water use efficiency are important variables of crop varieties. To date there have been no reports published on WUE of pigeonpea grown in the US. We found that transpiration rates varied among all four varieties and planting dates, but not among densities. W1 consumed less water, but also had lower water use efficiency. W3 had a significant higher WUE (5.66 µmol CO_2/mmol H_2O) than G2 and W1, but was similar to G2. The values were lower than those for sorghum, higher than for wheat and comparable to cotton and soybean [30-32]. For example, Xin *et al.* (2009) reported that WUE varied from 12.73 to 15.65 µmol CO_2/mmol H_2O among 25 sorghum lines [32]. WUE of wheat ranged from 2.0 to 3.7 µmol CO_2/mmol H_2O [30]. WUE varied among temperature and CO_2 treatments and ranged from about 2 to 5 µmol CO_2/mmol H_2O for cotton [33] and 2 to 7 µmol CO_2/mmol H_2O for soybean [31].

3.2. Leaf Area Index (LAI)

Both planting dates and plant densities had no influence on LAI (**Tables 2** and **4**). The mean LAI for all plots was 2.17 m^2/m^2. There was no significant difference in LAI between G1 and W3 or between G2 and W2. LAI of G1 and W3 were significantly higher than for G2 and W1 (**Table 3**). G1 and W3 were the two taller species than G2 or W2, which grew shorter. The values for LAI were smaller, but within the range reported for LAI for pigeonpea. For example, Lopez *et al.* (1997) reported that LAI varied from 1.3 to 4.9 m^2/m^2 of seven genotypes of pigeonpea for the control treatment and 0.6 to 3.6 m^2/m^2 under the water stress treatment [7]. Balakrishnan *et al.* (1987) reported a critical LAI of 5.3 m^2/m^2 among six pigeonpea varieties, but found that the crop growth rate was influenced more by the net leaf photosynthesis rate than for LAI [34].

3.3. Soil Respiration

No significant difference was observed among planting dates, or densities, or varieties (**Table 1**). The mean soil respiration rate was 3.23 µmol $CO_2/m^2/s$. One thing should be noted is that soil moisture was very low when the soil respiration measurements were taken. The value measured in the pigeonpea field was similar to that in a nearby grassland measured at similar times, and in the range of those reported for crop fields [35,36].

4. CONCLUSION

We investigated the effects of planting dates, planting densities and varieties on ecophysiology of pigeonpea in Southeastern US We found significant differences in maximum net leaf photosynthesis, stomatal conductance, transpiration, WUE, and LAI among all four varieties. Plants in the late planting plots had higher leaf photosynthesis, but used more water, resulting in a lower WUE. Higher WUE of plants in early planting plots could be attributed to lower stomatal conductance and lower transpiration losses. LAI was not influenced by the planting dates. Soil respiration was not influence by the planting dates, planting densities and varieties. No variable investigated in this study was influenced by the planting densities. Based on these results, we conclude that late plating with variety G1 or W3 produced higher biomass and yield, had high WUE, and had no significant influence on soil CO_2 emission.

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